Effect of Neck Refrigeration by the Neck Cooler on Worker's Physiological and Psychological Performance

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Abstract. Intelligent neck cooler has been proposed as an energy-saving indoor air-conditioning method by direct cooling of human body. This paper reports evaluation results of intelligent neck cooler's effectiveness regarding labor productivity and comfort in hot summer office environment. We studied through trial subjects how neck cooling affects physiology, psychology, and task productivity in summer heat environment. Higher comfort level were reported (0.05 statistical significance), and better maintenance of attention (0.01 statistical significance) in long lasting tasks in neck cooling condition were demonstrated.

Keywords: Neck cooling · Mental performance · Comfort technology · Energy-saving technology · Wearable environment

1 Introduction

In Japan, comfortable lifestyle and environment realized by abundant electric power broke down after March 11 2011. This has been accompanied by augmentation of heatstroke or hypothermia risks, as well as deterioration of labor productivity. A method has been proposed to avoid decline of both task productivity and comfort. It is an energy-saving method for indoor air-conditioning that consist in cooling or warming directly human body [1]. Several researches reported that both local cooling and warming affect physiological indices variations [2, 3, 4]. Also, neck cooling causes variations in brain temperature and brain blood flow [5, 6]. In this study, we investigated effectiveness of direct neck cooling in summer conditions office environment.

2 Change of Sweating Start Room Temperature by Neck Cooling

The environment of a typical Japanese office space in summer heat can be reproduced using the room shown in Fig. 1. Subjects of the experiment were sat in the room in both normal condition and neck cooling condition. Subjects were four men from thirties to

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forties, and one woman in her thirties. All subjects were healthy. Heat sensation, comfort/discomfort sensation, and sweat were evaluated using both self-assessment by a Visual analog scale (VAS) and peripheral physiological information (sweat, heart rate variability). Thermic sensation and comfort/discomfort sensation were self-assessed every 10 min using VAS shown in Fig. 2. Thermic sensation scale ranges from 0 for cold sensation to 10 for hot sensation. In the same way, comfort/discomfort scale ranges from 0 for discomfort to 10 for comfort. All subjects wore underwear, a full-length pants, and a short-sleeved shirt without neck-tie (standard “cool-biz” dress code in Japan). Sweating start and sweat amount were measured by difference method using a ventilated capsule-type sweat sensor (SNT-200, Rousette Strategy Inc.).

Fig. 1. Environment control room.

Fig. 2. VAS used for evaluation of thermal sensation and comfort/discomfort feeling

We defined sweating start room temperature as the temperature of the room when sweat amount of subject increases considerably. We compared the sweating start room temperature of each subject when neck cooling was performed or not (Fig. 3). We can see in Fig. 3 that in the case of four among five subjects sweating start temperature was considerably higher when neck cooling was performed.

3 Evaluation of Comfort Level by Neck Cooling

Figures 4 and 5 show an example of variations of sweat amount and VAS evaluation for the same subject during this trial run. Figure 4 shows these variations in normal condition, while Fig. 5 shows these variations when using neck cooling. According to VAS evaluation, both discomfort sensation and heat sensation increase together with room temperature elevation. The same trend was observed for all five subjects. We can

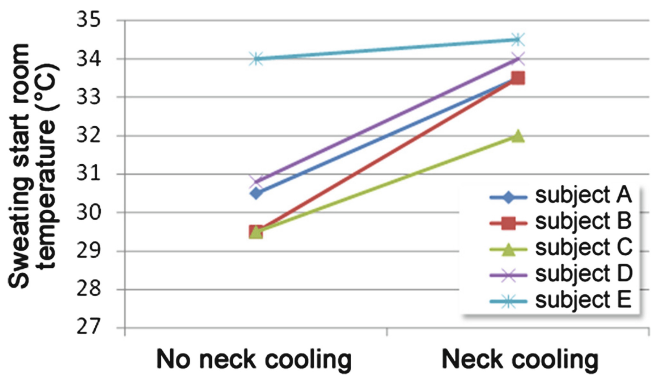

Fig. 3. Change of sweating start room temperature by neck cooling

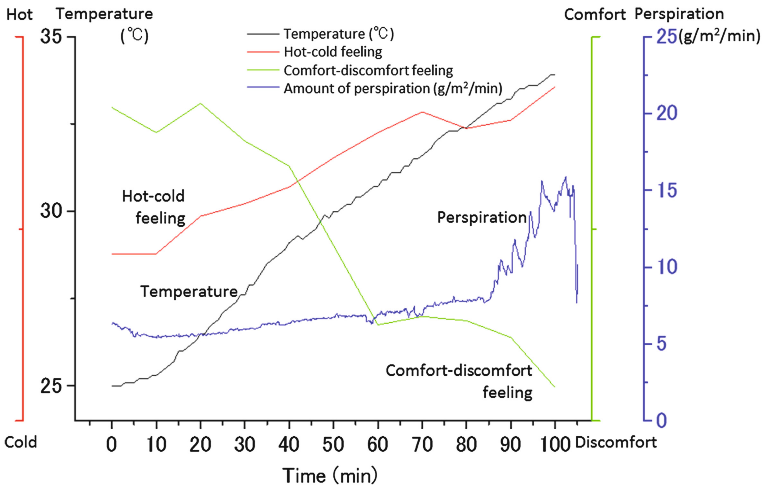

Fig. 4. Comfort/discomfort feeling and sweat amount variations due to room temperature elevation without neck cooling

understand that there is a correlation between environment temperature and comfort regarding temperature sensation.

Also, Fig. 6 shows the relation between heart rate variability as sympathetic nervous system activity index and comfort/discomfort by VAS evaluation when a subject is sweating or not. Power ratio of low frequencies and high frequencies in heart rate variability (LF/HF) was used as sympathetic nervous system activity index. A high value of LF/HF represents a state when the activity of sympathetic nervous system is dominant compared to parasympathetic nervous system. We can observe that when subject is sweating he is in an uncomfortable state, and LF/HF value is high. We see that discomfort sensation due to sweating can be demonstrated by heart rate variability analysis.

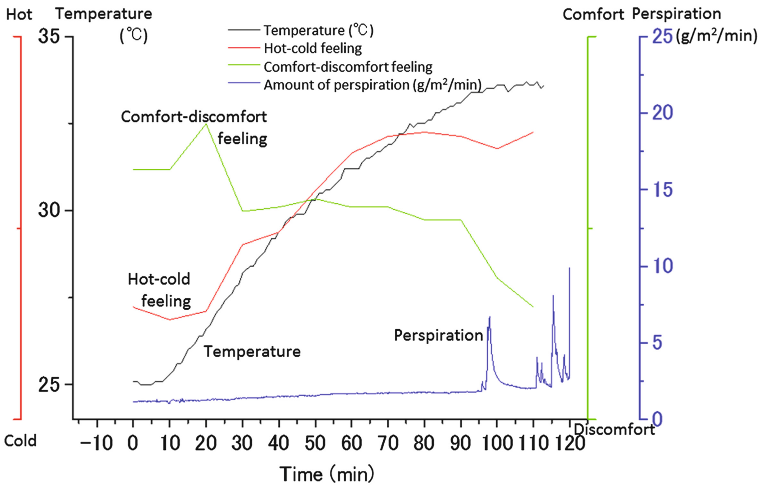

Fig. 5. Comfort/discomfort feeling and sweat amount variations due to room temperature elevation with neck cooling

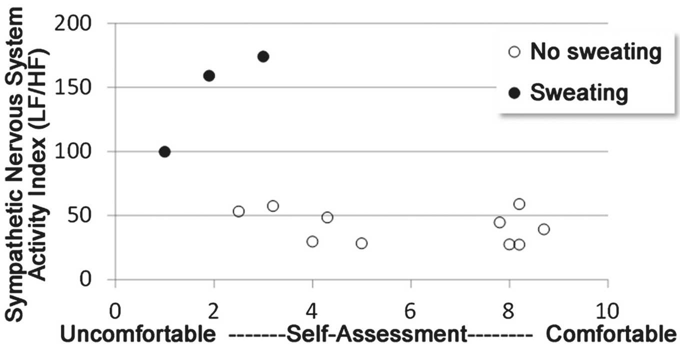

Fig. 6. Relation between comfort/discomfort sensation and sympathetic nervous system activity index when sweating or not

Furthermore we carried out a second experiment in the environment control room set to keep temperature at 31 °C, relative humidity of 50 %, and wind velocity at 0.15 m/s, re-creating summer heat office environment. The purpose of this experiment was to compare the subjects' state in normal condition and in neck cooling condition. Subjects were nine men from twenties to forties, and four woman in their twenties. All subjects were healthy. They wore underwear, a full-length pants, and a short-sleeved shirt without neck-tie. In both conditions, subjects were accommodating themselves to the environment by spending more than 30 min in a typical comfortable room temperature level (22 °C) before entering the environment control room. Occurrence of sweating and sweat amount were measured by difference method using a ventilated capsule-type sweat sensor as in the preliminary experiment.

First of all, we compared the VAS self-assessment for comfort/discomfort in both normal and neck cooling conditions 100 min after entering the environment control room. Figure 7 shows that more than half of the 12 subjects self-assessed a higher comfort level in neck cooling condition. Moreover, Student's *t*-test (two-tailed test) confirmed statistical significance (0.05 level) of comfort level difference between normal and neck cooling conditions.

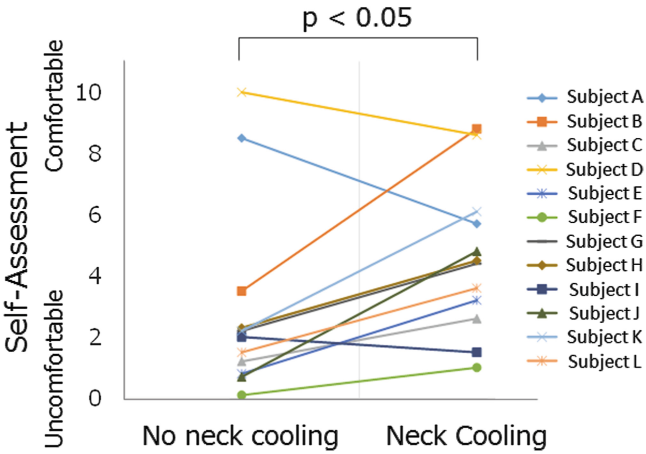

Fig. 7. Effect of neck cooling on comfort sensation in a summer heat room (VAS evaluation)

4 Neck Cooling Effect on Attention Keeping in Hot Environment

Finally we investigated the effect of neck cooling on task productivity. Task productivity was evaluated using the Conners' Continuous Performance Test, Second Edition (CPT II). It is a valuable assessment tool that can reveal important information about an individual's functioning, generally used for diagnosis of attention-deficit/hyperactivity disorder (ADHD). Such, CPT II is adequate to evaluate attention keeping during a task, which is related to task productivity. We adapted CPT II such subjects were told to press the space bar as quickly as possible when they are presented with a pre-defined number (target stimulus) among randomly presented numbers. Test performance is evaluated by measuring the reaction time between the target stimulus presentation and space bar is pressed.

In this experiment, we evaluated attention keeping by measuring the average reaction time and reaction time coefficient of variation of 80 target stimuli among 240 non-target stimuli. 10 subjects who felt uncomfortable in summer heat office space performed the test in both normal and neck cooling conditions. The experiment Results are reported in Table 1. We can see that both average reaction time and its coefficient of variation are lower in neck cooling condition than in normal condition. Two-tailed student's *t*-test demonstrated statistical significance of reaction time coefficient of

Table 1. Average reaction time (left) and reaction time coefficient of variation (right) of CPT II

	Average Reaction Time (msec)	
	Neck Cooling	No neck cooling
Average	458	471
σ	44	46
Min	386	404
Max	528	534
Nb samples	10	10

	Coefficient of Variation	
	Neck Cooling	No neck cooling
Average	17.6	21.8
8σ	4.7	5.5
Min	11.7	12.3
Max	25.4	31.2
Nb samples	10	10

variation difference in normal and neck cooling conditions (0.01 level). Average reaction time difference significance could not be statistically approved.

5 Conclusion

We evaluated through trial subjects experiments how neck cooling affects physiology, psychology, and task productivity in summer heat environment.

- Sweating start room temperature was increased by neck cooling in the case of four subjects among five. The average temperature increase was 3.2 °C.
- In summer heat environment, more than half of the 12 subjects reported significantly higher (0.05 level) comfort level in neck cooling condition.
- Neck cooling was demonstrated to be effective for continuous maintenance of attention in long lasting tasks. Reaction time coefficient of variation of CPT II was significantly lower (0.01 level) in neck cooling condition than in normal condition.

Experimental results of this study show that using neck cooling in summer heat office, air-conditioner can be turned off or temperature set higher, without affecting comfort and labor productivity.

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